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ABSTRACT

This paper presents a two dimensional chart of student behavior and subject matter content for facilitating the development of the Individually Prescribed Instruction (IPI) science curriculum, or any science curriculum. Within this framework, behavioral objectives are formulated, science subject matter content is selected, student learning experiences are designed, and evaluation procedures are planned. Incorporated in the schema is a unique delineation of student behaviors with respect to the processes of scientific inquiry and these are integrated with categories of the student's cognitive behavior as it pertains to science learning. Included also in the behaviors dimension are the student's attitudes and interests and his orientation to the relationships between science and other aspects of culture. In the content dimension, the discussion includes new explications of the nature of scientific inquiry and the social aspects of science. (Author/EK)

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STUDENT BEHAVIOR AND SCIENCE CONTENT CATEGORIES AND SUBCATEGORIES FOR A SCIENCE PROGRAM

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STUDENT BEHAVIOR AND SCIENCE CONTENT CATEGORIES AND SUBCATEGORIES FOR A SCIENCE PROGRAM

by

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Preface

This paper presents a schema for facillitating the development of the Individually Prescribed Instruction (IPI) science curriculum, or any science curriculum. Within the framework of this schema, behavioral objectives may be formulated, science subject-matter content may be selected, student learning experiences may be designed, and evaluation procedures may be planned.

The idea of a two-dimensional chart of student behaviors and subject-matter content is not new, nor is this the first attempt to compose a taxonomy of student behaviors or a categorization of the subject-matter of science. The schema presented here is indebted for its form to the work of Ralph Tyler (cf. Tyler, 1950) and much of its organization derives from the Taxonomy of Educational Objectives (Bloom, 1956; Krathwohl, Bloom, and Masia, 1964), while efforts to classify the content of science go back to Aristotle. Nonetheless, this scheme is more than a compilation of other people's work. Incorporated in it is a unique delineation of student behaviors with respect to the processes of scientific inquiry, and these are integrated with other categories of the student's cognitive behavior as it pertains to science learning. Included also in the behaviors dimension are the student's attitudes and interests and his orientation to the relationships between science and other aspects of culture. In the content dimension, the discussion includes new explications of the nature of scientific inquiry and the social aspects of science. These features, among others, should contribute to the usefulness of this schema for developing a science curriculum suited to the demands of the 1970's.

The substance of this paper has benefitted from many conversations with colleagues at LRDC and elsewhere, and I am grateful for this sustenance.

L.E.K.

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STUDENT BEHAVIOR AND SCIENCE CONTENT
CATEGORIES AND SUBCATEGORIES FOR A SCIENCE PROGRAM

Introduction

Consider a two-dimensional chart, such as Figure 1, where categories of student behavior are listed along one dimension and categories of science content are listed along the other. If the categories of behavior and content have been well designed, it should be possible to place any instructional objective, any science lesson, any student science activity, any test item in the cells of the chart. The largest part of this document consists of descriptions of categories and subcategories of student behavior and science content for a two-dimensional master chart that can be useful in conceptualizing and organizing the numerous facets of the IPI Science Program. The master chart itself is too bulky in its present form to be included here, but it is really nothing more grand than what Figure 1 would look like with all subcategories filled in.

The categories and subcategories of student behavior are listed in Table 1 on pages 2-5 and are discussed in the succeeding pages. These discussions seek to delineate what is included in each subcategory, but they are not exhaustive. Actually, each subcategory is made up of component behaviors, which can probably be arranged in a hierarchy. Discussion of the science content subcategories begins on page 40. The content subcategories are further divided into content areas, and each of these has numerous component topics and ideas. Again, the listings of these are not exhaustive. Suggestions are always welcomed for improvements in the student behavior and science content categories and subcategories and for increasing the clarity of the discussions.

Figure 1

Two-Dimensional Chart of Student Behaviors and Science Content

CONTENT	STUDENT BEHAVIORS								
	A. KNOWLEDGE AND COMPREHENSION	B. PROCESSES OF SCIENTIFIC INQUIRY I: OBSERVING AND MEASURING	C. PROCESSES OF SCIENTIFIC INQUIRY II: SEEING A PROBLEM AND SEEKING WAYS TO SOLVE IT	D. PROCESSES OF SCIENTIFIC INQUIRY III: INTERPRETING DATA AND FORMULATING GENERALIZATIONS	E. PROCESSES OF SCIENTIFIC INQUIRY IV: BUILDING, TESTING, AND REVISING A THEORETICAL MODEL	F. APPLICATION OF SCIENTIFIC KNOWLEDGE AND METHODS	G. MANUAL SKILLS	H. ATTITUDES AND INTERESTS	I. ORIENTATION
1. BIOLOGICAL SCIENCES 1.100 BIOLOGY OF THE CELL 1.200 BIOLOGY OF THE ORGANISM 1.300 BIOLOGY OF POPULATIONS									
2. PHYSICAL SCIENCES 2.100 CHEMISTRY 2.200 PHYSICS 2.300 EARTH AND SPACE SCIENCES									
3. GENERAL 3.010 NATURE OF SCIENTIFIC INQUIRY 3.020 SOCIAL ASPECTS OF SCIENCE 3.030 HISTORICAL DEVELOPMENT OF SCIENCE 3.040 BIOGRAPHIES OF SCIENTISTS 3.050 MATHEMATICS IN SCIENCE 3.060 MEASUREMENT 3.070 SYSTEMS									

Table 1

STUDENT BEHAVIORS

A. KNOWLEDGE AND COMPREHENSION

A.01 Knowledge of specific facts

A.02 Knowledge of scientific terminology

A.03 Knowledge of concepts of science

A.04 Knowledge of conventions

A.05 Knowledge of trends and sequences

A.06 Knowledge of classifications, categories, and criteria

A.07 Knowledge of scientific techniques and procedures

A.08 Knowledge of scientific principles and laws

A.09 Knowledge of theories or major conceptual schemes

A.10 Identification of a fact, concept, procedure, classification scheme, or theory in a new context

A.11 Translation of a fact, term, concept, trend, principle, or theory presented in one symbolic form to another symbolic form

B. PROCESSES OF SCIENTIFIC INQUIRY I: OBSERVING AND MEASURING

B.01 Observation of objects and phenomena

B.02 Description of observations using appropriate language

B.03 Measurement of objects and changes

B.04 Selection of appropriate measuring instruments

B.05 Estimation of measurements and recognition of limits in accuracy of measurements

C. PROCESSES OF SCIENTIFIC INQUIRY II: SEEING A PROBLEM AND SEEKING WAYS TO SOLVE IT

C.01 Recognition of a problem

C.02 Formulation of a working hypothesis

C.03 Selection of suitable tests of a hypothesis

C.04 Design of appropriate procedures for performing experimental tests

D. PROCESSES OF SCIENTIFIC INQUIRY III: INTERPRETING DATA AND FORMULATING GENERALIZATIONS

D.01 Processing of experimental data

D.02 Presentation of data in the form of functional relationships

D.03 Interpretation of experimental data and observations

D.04 Extrapolation, when warranted, of functional relationships beyond actual observations, and interpolation between observed points

D.05 Evaluation of hypothesis under test in the light of the experimental data obtained

D.06 Formulation of appropriate generalizations (empirical laws or principles) that are warranted by the relationships found

E. PROCESSES OF SCIENTIFIC INQUIRY IV: BUILDING, TESTING, AND REVISING A THEORETICAL MODEL

E.01 Recognition of need for a theoretical model to relate different phenomena and empirical laws or principles

E.02 Formulation of a theoretical model to accomodate the known phenomena and principles

E.03 Specification of phenomena and principles that are satisfied or explained by a theoretical model

E.04 Deduction of new hypotheses from a theoretical model to direct observations and experiments for testing it

E.05 Interpretation and evaluation of the results of experiments to test a theoretical model

E.06 Formulation, when warranted by new observations or interpretations, of a revised, refined, or extended theoretical model

F. APPLICATION OF SCIENTIFIC KNOWLEDGE AND METHODS

F.01 To new problems in the same field of science

F.02 To new problems in a different field of science

F.03 To problems outside of science (including technology)

G. MANUAL SKILLS

G.01 Development of skills in using common laboratory equipment

G.02 Performance of common laboratory techniques with care and safety

H. ATTITUDES AND INTERESTS

H.01 Manifestation of favorable attitudes toward science and scientists

H.02 Acceptance of scientific inquiry as a way of thought

H.03 Adoption of habits of thought which ideally characterize scientists when engaged in inquiry ("scientific attitudes")

H.04 Enjoyment of science learning experiences

H.05 Development of interests in science and science-related activities

H.06 Development of interest (for some students) in persuing a career in science or in science-related work

I. ORIENTATION

I.01 Distinction between various types of statements in science (e.g., observation, interpretation, law, theory) and their relationship to one another

I.02 Recognition of the limitations of scientific explanation and of the influence of scientific inquiry on general philosophy

I.03 Historical Perspective: Recognition that the past, present, and future development of science is a product of its own history and a reflection of the general culture of its time

I.04 Realization of the relationships existing among scientific progress, technical achievements, and economic development

I.05 Awareness of the social and moral implications of scientific inquiry and its results for the individual, community, nation, and the world

Note on Subcategory Numbers

In references to the subcategories in the discussions which follow, the zero in the ten's digit place (e.g., as in A.01, B.04, F.03, etc.) is omitted.

Student Behaviors

The instructional objectives which the framers or teachers of a science course or program wish to attain can be expressed in terms of behaviors that students are expected to exhibit. Such student behaviors are categorized in the horizontal dimension of the master chart. While no scheme of categorization is perfect or will satisfy everyone, the scheme adopted here successfully accomodates the full range of student behaviors which may be sought as outcomes of science instruction in elementary and secondary schools. Some of the categories included in this scheme will be familiar to those readers acquainted with the Taxonomy of Educational Objectives, Handbook I (Bloom, 1956), but a main focus of the scheme is on categories of student behaviors related to carrying out the processes of scientific inquiry. This focus is justified, not only because the contemporary trend of science education is toward an emphasis on the processes of inquiry, but because science is meaningfully and significantly conceived as a system of inquiry, rather than simply as structured knowledge. Our scheme of categories also incorporates other student behaviors uniquely associated with the learning of science; viz., the student's skills in performing laboratory work, the student's attitudes toward science, and the student's orientation to science's relationships to other aspects of culture and to the individual.

A. Knowledge and Comprehension

This category refers to the knowledge and comprehension of science subject-matter that the student obtains solely or almost exclusively from reading books, from listening to lectures, and from other secondary sources. These are all legitimate sources of scientific information, both for the student and for the

working scientist, and there is no intention to imply here that knowledge and comprehension should not be acquired from secondary sources in the course of science instruction. It is intended, however, to differentiate these sources of knowledge from the student's acquisition of scientific information by empirical procedures (category B) and his formulation of concepts, generalizations, and theories through involvement in inquiry (categories D and E). To the extent that any instructional program employs books, films, lectures, or other media to convey science subject-matter, and virtually no existing programs do not, there will be more or fewer entries under the Knowledge and Comprehension category. The behaviors suggested by this category are, first, that the student has acquired the specified information and, second, that he can recall it when asked to do so (subcategories A.1 to A.9) and that he can demonstrate comprehension of the information by identifying it in a new context or by manipulating it (subcategories A.10 and A.11). The first nine subcategories are derived largely from the Knowledge classification in the cognitive domain of the Taxonomy of Educational Objectives, which provides an excellent framework for delineating the various types of science subject-matter knowledge that a student may learn.

A honeybee has six legs. Limestone floats on mercury. In the United States, the days are longer than the nights between 21 March and 23 September. These are illustrations of facts which a student in science might be expected to know, and they illustrate subcategory A.1, Knowledge of specific facts, under the Knowledge and Comprehension category. Specific facts that students could learn are countless, and success in learning and recalling some facts is an expectation of almost all science programs and courses at every level of sophistication. As the level of sophistication increases, the facts to be learned tend to incorporate an increasing number of scientific terms, concepts, and conventions, but

knowledge of these is itself often considered an objective of instruction. Subcategory A.2, Knowledge of scientific terminology, is concerned with correct definition and use of terms that have become established in the scientist's vocabulary. To illustrate, the head, thorax, and abdomen are the three parts of the body of a honeybee; limestone is a mineral; 21 March is called the vernal equinox, 23 September the autumnal equinox.

The next subcategory, A.3, Knowledge of concepts of science, is likewise concerned with definition and correct usage. Though there is no general agreement on what constitutes a "concept" in science, concepts of science are taken here to mean those abstractions of observed phenomena or relationships which scientists have found to be continually useful in investigating the natural world and for which they have agreed upon exact definitions. In this sense, "concepts of science" includes both fairly limited scientific ideas, such as density, chemical element, diffusion, symbiosis, germination, and larger scientific ideas, such as cycle, system, force, equilibrium, adaptation. The intent in subcategory A.3, however, is to stop short of those ideas which are represented by major conceptual schemes or theories (see subcategory A.9 below). For subcategory A.4, Knowledge of conventions, the focus is on the student's correct usage and interpretation of signs, symbols, abbreviations, and practices that have been adopted in a science discipline to represent certain entities and relationships. Some illustrations from physics are: $\vec{v} \dashv\vdash {}_{92}U^{238}$ from chemistry: $Ag^{+} + Cl^{-} \rightleftharpoons AgCl$

from genetics: Aa x AA

Knowledge of trends and sequences, subcategory A.5, refers to the student's ordering of phenomena in the correct sequence of their occurrence in nature or under experimental manipulation. The life cycle of the honeybee proceeds through successive stages from birth to death. The action of acidic ground water on

limestone mountains over time tends to produce hollow caverns and leads to the formation of stalactites and stalagmites. In the northern hemisphere, days become progressively longer than nights between the vernal equinox and the summer solstice. Subcategory A.6, Knowledge of classifications, categories, and criteria, refers to the student's ordering of objects and phenomena in accordance with the organizing structures established by scientists in a discipline, and his recognition of the characteristics or properties that determine the placement of an object or phenomenon in a particular category. The honeybee is classified as an insect; its six legs and three-part body are criteria for placing it in this category. Mercury is classified as a liquid; at ordinary temperatures, it flows readily and takes the shape of its container. In these properties, it is different from a solid, such as limestone, and from a gas, such as carbon dioxide. Since mercury cannot be broken down into any simpler substances by ordinary chemical means, it is classified as a chemical element, and since limestone can be, it is a chemical compound.

Knowledge of scientific techniques and procedures, subcategory A.7, should be distinguished from the student's actual performance of laboratory techniques (category G, Manual Skills), and from his use of scientific techniques and procedures in inquiry (categories B through E). Similarly, in subcategories A.8 and A.9, the intent is to focus on the knowledge of scientific principles, laws, and theories which the student has acquired, rather than on his formulation of these abstract ideas through inquiry (categories D and E). Among the myriad of procedures and techniques used by scientists, the student may be asked to recall and describe how the specific gravity of mercury can be determined, or how the growth and division of cells in a honeybee's body can be studied, or how the exact time of the vernal equinox is found. Also included in subcategory A.7 is knowledge of the general procedures employed by scientists in conducting inquiries,

the processes of scientific inquiry. Subcategory A.8 includes the acquisition and recall by the student of a particular scientific principle or law, which is defined as a generalization derived and established by scientists on the basis of a large number of observations of phenomena. Archimedes' Principle is a generalization of many observations relating to floating objects. Mendel's Laws are generalizations of observations of inherited characteristics in many plants and animals. The student's knowledge of the most abstract formulations in science, its theories or major conceptual schemes, is placed in subcategory A.9, the last of our recall classifications. In this subcategory are found the significant organizing and explanatory ideas of every scientific field, such as the theory of evolution, the kinetic-molecular theory, the orbital model of the atom, the general theory of relativity.

Beyond simply recalling something when prompted to do so, the student may demonstrate that he has acquired an item of knowledge in situations that do not probe directly for it. A successful demonstration of this sort is usually taken as evidence that the student has some comprehension of the item of knowledge in question. Under subcategory A.10, the student demonstrates that he can identify a fact, concept, procedure, classification scheme, criterion for classification, principle, or theory when it is presented in a new context, i.e., one which differs from the context in which the original instruction was given. For example, a science student may have learned the concept of a cycle in the context of the stages in the lives of flowering plants from seed to seed, and when presented with information about the evaporation of water from lakes and oceans, the condensation of water in clouds, the falling to earth of water as rain, and the eventual collection of run-off water in lakes and ocean, he identifies this closed series of stages relating to water as a cycle. A student, who has learned the criteria for classifying organisms as insects when studying

honeybees, identifies these criteria in given information about grasshoppers to decide that they also are classified as insects. Another way for the student to demonstrate comprehension is by successful translation. Under subcategory A.11, the student demonstrates that he can translate a fact, term, concept, convention, trend, principle, or theory presented in one symbolic form to another symbolic form. To illustrate, given a verbal description of the focus involved in the situation of a horse pulling a wagon over a rough road, the student translates this information into a vector diagram showing the interacting forces. Given the chemical equation for any reaction, the student translates it into a verbal statement about the reaction. Finally, it should be noted that the demonstrations of the student's comprehension of knowledge, which are included here under category A, are not the same as demonstrations of application, category F, where the emphasis is on the student's utilization of his knowledge to solve new problems.

B. Processes of Scientific Inquiry I: Observing and Measuring

This category and the following three focus on the behavior of the science student involved in inquiry. The ordering of these four categories is not fortuitous, but represents successively greater involvement in the processes scientists employ to investigate the natural world and to construct new ideas. Starting in category B with Observing and Measuring, which in any given instance may or may not be a prelude to the investigation of a problem, (and which include behaviors that might actually be presented as exercises in an instructional program), the student engaging in inquiry would move generally through the stages of categories C to E. By formulating and reformulating a theoretical model in category E, the student at this stage may become involved in aspects of "fluid enquiry," in contrast to the more common "stable enquiry" of the preceding stages (cf. Schwab, 1962). A cautionary note, nevertheless, is in order. These four categories are offered as a taxonomy of student behaviors related to the processes of scientific inquiry, and they are not meant to be a prescription for conducting inquiries. It is likely that many of the behaviors given in the subcategories could be observed at some time when an inquiry is proceeding, but it is not claimed that all the behaviors will be observed in the course of every inquiry nor that they will always occur in the order in which the subcategories appear here.

In indicating the content and scope of the subcategories in this and the following three categories, illustrations will be drawn chiefly from inquiries relating to heat phenomena. These phenomena offer a fruitful area for inquiry by science students with varying degrees of sophistication, from the early elementary school grades right on up through high school. Heat phenomena, moreover, are familiar to the student in his everyday experiences, which can provide initial observations and questions for investigation.

Representative examples of the Observation of objects and phenomena, subcategory B.1, would find a student watching an ice cube placed in a glass of water in a warm room or another student noting changes of the water in a beaker that is being heated on a hot plate. For either of these situations, several dozen discrete things can be observed in a few minutes, and the oral or written communication of these observables constitutes the next subcategory, B.2, Description of observations using appropriate language. The emphasis here is on the effectiveness of the communication of the observations, rather than on the form of the language used, which could vary widely depending upon the level of sophistication attained by the student, but could still communicate accurately what he observed. "The outside of the glass got wet" is as appropriate a description by a young student of an observation on the ice cube in water system as "Moisture accumulated on the glass's outer surface" is for an older student.

When the student's observations go beyond being only qualitative and beyond simple counting and when he employs any instrument to make them, his behavior represents subcategory B.3, Measurement of objects and changes. In the ice cube in water system, the initial temperature of water was measured with a thermometer and found to be 22°C. The temperature of the water in the beaker being heated on a hot plate changed from 22°C to 24°C after one minute, to 27°C at the end of the second minute, to 30°C at the end of the third minute. To obtain the data he is seeking in any measurement, the student must select the appropriate measuring instrument (subcategory B.4), appropriate in the sense that the instrument is capable of measuring the desired quantity and appropriate in that it is operative over the range of the quantity to be measured. A stop watch is <u>not</u> the appropriate instrument for measuring the temperature of water in a beaker; a mercury-in-glass thermometer is <u>not</u> appropriate for

measuring the temperature of a melt in a blast furnace. Lastly, subcategory B.5 concerns the student's taking account of the calibration markings of a measuring instrument. He should recognize that the accuracy in measuring a quantity with a particular instrument is limited by the smallest division shown on its scale, and, when he makes measurements with that instrument, he estimates the values of the next subdivision between the smallest division shown. If a thermometer is calibrated with one degree divisions, its limit of accuracy is whole numbers of degrees, but a student may estimate the temperature of a liquid with this thermometer to be, for example, 28.5°C. Also included under subcategory B.5 is the significant figures convention that a more advanced science student is expected to use for indicating accuracy when he records and manipulates measurements.

C. Processes of Scientific Inquiry II: Seeing a Problem and Seeking Ways to Solve it.

A beaker of water has been heated to 80°C on a hot plate. Leaving the thermometer in the water, the student removes the beaker from the hot plate and places it on his desk. After five minutes, the thermometer reads 72°C. Since the water has lost some heat without anything being done to it, the student recognizes that he has a problem. He wishes to investigate heat phenomena in liquids and this will be difficult if he has to contend with apparently spontaneous losses of heat from his liquid samples to the surrounding air. He must minimize such heat losses to carry out his investigation, and his problem is how to accomplish this. What materials should he use for the containers that hold his liquid samples? Is heat loss through the walls of a container the same for all materials?

A student's recognition of a problem (subcategory C.1) may pass through several stages, as the foregoing illustration suggests, from an awareness of the problem area to the identification of a specific problem that can be investigated experimentally. The last question in the preceding paragraph is a specific problem susceptible to experimental investigation, and it might quickly lead the student to the formulation of a working hypothesis (subcategory C.2) that would give direction to the investigation. He might hypothesize, for example, that heat is lost more readily through the walls of containers made of some materials than through the walls of containers made of other materials. An alternative, equally plausible hypothesis might be that the amount of heat lost depends on the thickness of the walls of the container and not on the material of which the container is made. Whatever his hypothesis may be, the student next takes steps to determine whether or not it is correct.

The selection of suitable tests of a hypothesis, subcategory C.3, involves choosing a particular empirical approach or a series of experiments that logically can verify the hypothesis, if it is correct. This subcategory is concerned with the question of whether or not a proposed experiment constitutes a valid test of the hypothesis, and it is not concerned with an experiment's manipulative details or the construction and use of apparatus (except in so far as these might affect validity). These latter concerns are included under subcategory C.4, Design of appropriate procedures for performing experimental tests. To obtain a valid test of the hypothesis that the heat lost from a container depends on the thickness of its walls and not on the material of which the container is made, the student would have to employ a two-fold experimental approach. First, he needs to measure heat losses in containers made of the same material but with different wall thicknesses. Second, he needs to measure

heat losses in containers with exactly the same wall thickness but made of different materials. A suitable test of the alternative hypothesis, given in the preceding paragraph, that heat is lost more readily through the walls of containers made of some materials than through the walls of containers made of other materials, is more straightforward. The student would simply have to measure heat losses in containers made of different materials.

Before performing his experiments, the student designs and devises appropriate procedures (subcategory C.4) for measuring heat losses in containers made of different materials. One procedure could be: (1) obtain or make containers of exactly the same size and shape but of different materials, e.g., metals, glass, ceramic, solid plastic, foam plastic, paper; (2) fill each container to the same level with boiling water; (3) stir the water with a thermometer and record the water temperature; (4) continue stirring and record the water temperature every 60 seconds for a period of 30 minutes. In this illustration the equipment and procedures used are quite simple, but this is not so in many experiments that students may carry out. A determination of the velocity of light or of other electromagnetic radiations calls for complex apparatus and an elaborate protocol.

D. Processes of Scientific Inquiry III: Interpreting Data and Formulating Generalizations.

Experimental data are obtained by the student in the form of recorded observations and measurements, and he must usually process these data to yield values for the quantities under study. Subcategory D.1, Processing of experimental data, is concerned with the student's behavior in manipulating, adjusting, and organizing his observations and measurements. In a typical calorimetry

experiment to determine the amount of heat (in calories) gained by a sample of lead, the measurements recorded are the sample's mass (in grams), its initial temperature (in degrees C), and its final temperature; processing of these data include subtracting the initial from the final temperature and multiplying the difference by the sample's mass to yield the number of calories gained. In volumetric experiments with gases, processing of recorded data includes the adjustment of the actual measurements of volume to S.T.P. by using the recorded measurements of atmospheric pressure and room temperature. Other aspects of data processing that fall under subcategory D.1 are the organization of data in tables or in other readily readable formats and, for more advanced science students, the carrying out of an error analysis.

Subcategories D.2 and D.4 deal with the student's preparation of graphs and his use of graphs. In an experiment to measure the volume of a sample of air at different temperatures but under constant pressure, a student found that the volume of the sample was 18.7 cm^3 at a temperature of 100°C (or 373°K), 14.6 cm^3 at 20°C (or 293°K), 13.7 cm^3 at 0°C (or 273°K), and 11.6 cm^3 at -40°C (or 233°K). To make a presentation of these data in the form of a functional relationship, subcategory D.2, the student plots the data points on a sheet of graph paper with absolute temperature (in degrees K) on one axis and volume on the other axis. Since the points can be connected by a straight line, his graph shows the functional relationship between the two variables: volume of air is directly proportional to absolute temperature. Had the relationship not been linear, the curve of the graph would have shown a different shape. By plotting points for the observed values of variables on suitably ruled graph paper, a student can make a presentation of any functional relationship. Extrapolation, when warranted, of functional relationships beyond actual observations and interpolation between observed points, subcategory D.4, can also be made from a

graph. In the illustrative experiment, observations were made at 20°C and at 0°C, but the volume of air at 10°C (or 283°K) was not measured. Interpolating on the graph of the relationship reveals that the volume of the sample of air at 283°K was 14.2 cm^3. Similarly, extrapolating above the highest observed temperature and below the lowest observed temperature shows that the volume of the sample of air would be 21.2 cm^3 at 425°K and 8.6 cm^3 at 173°K. Both the interpolation and the two extrapolations are warranted here because there are no intervening conditions that alter the functional relationship between temperature and volume of air. An extrapolation to 73°K would not be warranted, however, because the air would have changed from a gas to a liquid before that temperature was reached and the temperature-volume relationship does not take into account this intervening condition.

Interpretation of experimental data and observations, subcategory D.3, is the first stage in the student's analysis of the results of his experiment. If the observations are qualitative, their interpretation involves collating them mentally and formulating a discrete concept of what the experimental results signify. If the data are presented in the form of a graph, their interpretation also includes formulating a conception of the trends or the functional relationship displayed and translating this information into equivalent verbal or symbolic form. In an experiment where the volume of a sample of oxygen gas was measured under different external pressures and at constant temperature, a graph of the data obtained was prepared. Interpreting this graph, a student was able to state that the volume of oxygen is inversely proportional to the external pressure at constant temperature or, in symbols, PV=k (at constant T). Besides interpreting data from his own experiments, the student may have occasion to interpret experimental findings obtained in inquiries of other persons, and such

occasions are also included under subcategory D.3.

A further stage in the student's analysis of the results of an experiment falls under subcategory D.5, Evaluation of a hypothesis under test in the light of the experimental data obtained. A valid test of a hypothesis having been selected, designed, and carried out, data having been collected, organized, and interpreted, it is time to check whether or not the findings verify the hypothesis. The student now must answer the question, "Is the evidence consistent with the hypothesis?" If experimental data show that the temperature of water in metal containers drops more than water in plastic containers over the same period of time, this evidence is consistent with the hypothesis that heat is lost more readily through the walls of containers made of some materials than through the walls of containers made of other materials, and that hypothesis has been verified. Parenthetically, the student behavior described in this subcategory was classified under "Analysis of Relationships" (4.20) in the Taxonomy of Educational Objectives, Handbook I (Bloom, 1956).

In an inquiry into the changes in the volume of air at different temperatures, a student has found the relationship that, at constant pressure, the volume of a sample of air is directly proportional to its absolute temperature. Does this finding represent a general principle applicable to all samples of air? Is this an empirical law covering all gases, not only air? In the course of answering these questions, the student engages in behaviors included under subcategory D.6, Formulation of appropriate generalizations (empirical laws or principles) that are warranted by the relationships found. He considers the results of experiments with other samples of air and carries out or checks the reports of other similar inquiries using different gases. If his original finding is corroborated, he is justified in formulating an empirical generalization: at

constant pressure, the volume of a gas is directly proportional to its absolute temperature. It should be noted that this stage in the student's analysis of the results of an experiment involves making comparisons with other results and deriving from all the evidence available an abstract relation covering a range of related phenomena. The outcome of the student's thinking, the generalization he formulates, is a synthesis (cf. subcategory 5.30, "Derivation of a Set of Abstract Relations," in the Taxonomy of Educational Objectives, Handbook I). By virtue of the quite complex behaviors a student exhibits in this and the preceding two subcategories of category D, it is reasonable to infer that higher mental processes are operating.

E. Processes of Scientific Inquiry IV: Building, Testing, and Revising a Theoretical Model.

As inquiry in any area of science proceeds, many observations and knowledge of many phenomena are accumulated, generalizing empirical laws and principles are formulated. When inquiries are carried out within the framework of an accepted conceptual structure, the investigator goes no further than the accumulation of knowledge or the formulation of principles. The investigator is engaging in "stable inquiry," as Schwab has termed it (cf. Schwab, 1964), and this type of inquiry characterizes most of the research of scientists and science students. There are some occasions, however, when the broad conceptual structure in an area of inquiry has not been established or when new findings call it into question, and it is then that an investigator can engage in "fluid inquiry." In this type of inquiry, the aim of research is not only to ascertain facts and to formulate principles, but to build a theoretical model that will satisfactorily interrelate and accomodate them. The science student, whose own conceptual structure is not yet fixed, can often engage in fluid inquiry, if care

is taken not to implant existing scientific theories as dogmas in his minds, and he can have experiences in building and testing theoretical models. Key aspects of these experiences are included in the student behaviors classified in category E.

Recognition of the need for a theoretical model to relate different phenomena and empirical laws or principles, subcategory E.1, refers to the student's acceptance of theory-building as a legitimate part of scientific inquiry. This behavior is aptly illustrated by an example of its negation. During the 19th century many chemists refused to give serious consideration to the atomic theory or any other theoretical model of matter. They asserted that the only proper concern of the science of chemistry are are macroscopic properties and changes that can be observed, and, eschewing speculative ideas, they based their science solely on various chemical laws and principles generalized from their laboratory experiences. Chemists today, on the other hand, like all scientists, recognize that empirical laws are not sufficient to organize and correlate all known phenomena, and they engage in the formulation of theoretical models, which serve three major functions in science. First, a theoretical model has a correlative function in that it ties together in a consistent, rational manner the various phenomena and generalizations in the area that it covers. In its explanatory function, a theoretical model is used to account for or explain the observations and generalizations in its area. The heuristic function of a theoretical model is to suggest new hypotheses, problems, and experiments that will give direction to further inquiries. When the science student is cognizant of these functions, he will be more apt to go beyond observations and empirical generalizations to the level of formulating and testing theoretical models.

Subcategory E.2, Formulation of a theoretical model to accomodate known phenomena and principles, identifies the first phase of the theory-building process. This phase, like the formulation of empirical generalizations (subcategory D.6), involves a synthesis of the student's knowledge to develop an abstract relationship, but he is now operating at a higher level of abstraction. The student tries to formulate a broad, general statement about the phenomena in an area of inquiry, and this statement will usually consist of a small set of postulates or assumptions about certain constituents or behaviors of nature. For example, after some time spent in investigating heat phenomena, the student might propose that the various observations and generalizations which were made can be explained by conceiving of heat as a fluid substance. This theoretical model of heat could be expressed in a set of postulates, like the following:

1. Heat is a colorless, odorless, invisible fluid substance.
2. Heat fluid occupies space and has mass, like other substances, but it has a very small mass.
3. Heat fluid flows spontaneously from regions of high concentration to regions of low concentration (from hot objects to cooler objects).
4. Heat fluid is always associated with matter and it increases disorder in the arrangement of particles of matter.
5. Heat fluid readily enters some gases, liquids, and solids, but it does not readily enter other gases, liquids, and solids.
6. When matter changes its state from solid to liquid or from liquid to gas, it absorbs heat fluid, and when matter changes its state from gas to liquid or from liquid to solid, it releases heat fluid.

If this theoretical model of heat has merit, the student can use it to account for or explain various heat phenomena. His specification of the phenomena and

principles that he can explain in this way is the behavior classified as subcategory E.3.

The analyses which the student makes under this subcategory, Specification of phenomena and principles that are satisfied or explained by a theoretical model, are quite similar to the analyses he makes in evaluating hypotheses (subcategory D.5), but here he is operating across an additional level of abstraction. When he is evaluating hypotheses, the student analyzes the relationship between a hypothesis and observational evidence, but here under subcategory E.3 he analyzes the relationship between a theoretical model and both generalized evidence, expressed as empirical laws and principles, and discrete observations. Examples of some observations and empirical laws regarding heat that are satisfied by the theoretical model given above are: metals are good conductors of heat but plastics are not -- explained by postulate 5; when water at $60^{o}C$ is added to water at $20^{o}C$, the resulting temperature of the water mixture is greater than $20^{o}C$ -- explained by postulate 3; the volume of a given quantity of any solid, liquid, or gas increases when it is heated -- explained by postulates 2, 3, and 4; additional heating is required to change water at $100^{o}C$ to steam at $100^{o}C$ -- explained by postulate 6; at constant pressure, the volume of a gas is directly proportional to its absolute temperature -- explained by postulates 2 and 4. The greater the number of observations and principles that are encompassed by a theoretical model, the more successful it is in fulfilling its correlative and explanatory function. If the student can specify many phenomena that are satisfied by the theoretical model he has formulated, he will have increased confidence in its adequacy.

The heuristic function of a theoretical model is exemplified in the next subcategory, E.4, of student behaviors, Deduction of new hypotheses from a

theoretical model to direct observations and experiments for testing it. This phase of theory-building involves two identifiable mental operations. First, beginning with the statement of his theoretical model, the student reasons from and in terms of it to certain deductions (hypotheses) that the model logically suggests or implies. This mental process is not unlike the logical derivation by deduction of new propositions from a given set of theorems in geometry. Once he has deduced a new hypothesis, the student then proposes a plan of experiments and/or observations which will test the hypothesis. This mental operation was discussed under subcategory C.3, Selection of suitable tests of a hypothesis (q.v.). The significant difference between subcategories E.4 and C.3 is that here the proposed plan of inquiry serves not only to test the correctness of a hypothesis, but also to test the adequacy of the theoretical model from which the student generated the hypothesis. To illustrate, postulate 2 of the theoretical model given above states that heat fluid, like other substances, has mass, though its mass is very small. From this and from postulate 3, which asserts that a hot object contains more heat fluid than a cold object, a student could deduce the hypothesis that an object has a greater mass when it is hot than when it is cold. Since, by postulate 2, the mass of heat fluid is very small, the comparisons of the mass of the hot with the cold object would have to be made over a large temperature difference, say $100^{\circ}C$ or more, to test this hypothesis.

Another hypothesis a student might deduce from the theoretical model concerning heat fluid is suggested by postulate 5. According to this postulate, heat fluid readily enters some substances but does not readily enter some others. The student might deduce from this that a characteristic of different substances, say different metals, is their differing capacities to increase

their temperature when the same amount of heat is available. The hypothesis is that each kind of metal, for example, has a "specific heat" which can be used to identify it. For either of these illustrative hypotheses, as well as for many others that could be deduced from the heat fluid theoretical model, the student would next propose appropriate experiments and observations that will lead to a determination of whether or not the hypothesis is correct. The actual carrying out of the proposed plan of inquiry is not a part of the student's behavior included under subcategory E.4, and the indicated investigations may even be conducted by other persons. Such investigations would involve the processes of inquiry already described under subcategory C.4 and in categories B and D. Clearly, new cycles of inquiry have thus been stimulated by a theoretical model as it fulfills its heuristic function.

Like subcategory E.3, the student's behaviors included in subcategory E.5, Interpretation and evaluation of the results of experiments to test a theoretical model, involve analyses of relationships. In this subcategory, the student seeks to analyze the relationships between the empirical evidence obtained and the hypothesis tested and between the empirical evidence and the theoretical model from which the hypothesis was deduced. In addition, when these analyses are at hand, the student makes a judgment about the adequacy of the theoretical model itself. His judgment of the model's adequacy generally is based both on evidence of consistency and precision throughout the theoretical structure and on the degree to which it satisfies scientists' criteria for a "good" model. Scientists commonly base their evaluation of a theoretical model on two kinds of criteria, viz., analytical criteria related to how well the model fulfills its correlative, explanatory, and heuristic functions; and certain essentially aesthetic considerations about the model's parsimony, elegance, and persuasiveness.

In this phase of theory-building represented by subcategory E.5, the science student has opportunities to join with others in discussions and even arguments about the value of a theoretical model, since it is not unusual for controversies to ensue among scientists when competing models are being evaluated.

Suppose that a student has the results of a large number of experiments with many different metals which show that the "specific heat" of every metal tested differs from that of every other metal. These results confirm his hypothesis that each kind of metal has a "specific heat" which can be used to identify it, and this confirmation gives him some increased confidence in the heat fluid theoretical model from which he deduced the hypothesis. Another student, however, has the results of many careful experiments repeatedly carried out to test his hypothesis that an object has a greater mass when it is hot than when it is cold. In none of the experiments was an increase detected in the mass of an objected when its temperature was raised as much as 500°C. These results indicate that the student's hypothesis is not correct, and the failure to confirm it suggests that postulate 2 of the heat fluid theoretical model, which states that heat fluid has mass, is not correct. The student might now reason that the entire theoretical model which conceives of heat as a fluid substance is thrown into question. If heat fluid has no mass, he would say, it is inconsistent to assume that heat is a substance, since no other substance without mass is known. But, the case against the model is not decisive. As the first student, who has gained confidence in the heat fluid model, could argue, the mass of heat fluid may be much smaller than originally anticipated and it may actually be so small that the addition of heat fluid mass to the mass of an object in a temperature increase of only 500°C cannot be detected with the instruments used in the experiments. From this point on, a lively discussion evidently can proceed, as each student marshalls evidence, reasoned arguments, and judgments in the process

of interpreting the results of experiments and evaluating a theoretical model.

Through the accumulation of new observations, through the interpretation and reinterpretation of results of experiments, through discussions and debates, any theoretical model in science becomes modified and sometimes it is overthrown. The science student engaging in fluid inquiry will before long encounter the phase of theory-building when he finds it necessary to reformulate a theoretical model he has espoused. His behavior at this juncture is described by subcategory E.6, Formulation, when warranted by new observations or interpretations, of a revised, refined, or extended theoretical model. Depending upon the nature and extent of the new observations or interpretations, the student's reformulation of his theoretical model may range from a minor modification to major surgery. The thought processes he employs here are not essentially different, of course, from those required for his original formulation of a theoretical model, subcategory E.2. The additional requisite under subcategory E.6, however, is that his reformulation take into account the wealth of new experiences and ideas developed in the intervening phases of theory-building. Many observations and generalizations about heat were satisfactorily correlated and explained by the heat fluid theoretical model and hypotheses deduced from this model were confirmed by experiments. Other observations of heat phenomena and some derived hypotheses which were found to be incorrect suggested that the heat fluid theoretical model was inadequate and should be modified or rejected. In confronting the task of reformulating his theoretical model of heat, the student must incorporate all this information in his thinking and devise a model that will obviate the defects of the original one without sacrificing its positive features. He may refine or extend the heat fluid theoretical model by changing some of its postulates or by adding some, or he may revise his model entirely, for instance, by conceiving of heat as due to the notion of the particles of a

substance. Whatever route his reformulation takes, he must assure himself that his new model fulfills the correlative, explanatory, and heuristic functions and satisfies the criteria of parsimony, elegance, and persuasiveness expected of every acceptable theoretical model.

F. Application of Scientific Knowledge and Methods

Both in his everyday life and in the part of it which he spends on schoolwork, the student confronts new problems that he must solve. He frequently can proceed toward a solution of a problem by calling upon his repertoire of scientific knowledge and inquiry skills. The student may have acquired the knowledge and skills which he can use in solving a particular problem either from secondary sources (category A) or through his participation in inquiry (categories B through E). In either event, when he applies relevant scientific knowledge and methods to a new problem where the mode of solution is not specified, the student's behavior can be classified under category F, Application.

The behaviors involved when a student makes an application have been well described in the Taxonomy of Educational Objectives, Handbook I (cf. Bloom, 1956, pp. 120-123), and this formulation is adopted here. The three subcategories of category F present a rough typology of problems to which the student may apply his scientific knowledge and inquiry skills, and their order suggests increasing remoteness from the original learning situation where he acquired the knowledge or skill. Subcategory F.1, Application to new problems in the same field of science, represents the most common situation in which students are called upon to make applications in the school context where their courses are organized by science fields. A few illustrative problems, posed as questions, whose solutions call for the application of knowledge and skills from the same

science field are: Why does this light bulb in this electrical circuit light up when I open this switch? How can you find out whether or not this rooster has a deficiency of male hormones? What can you do to speed up this chemical reaction? Will peeling off the bark of this birch tree cause it to die? When the student uses a fact, concept, principle, theory, method that he has learned in one science field to solve a problem in another field, his behavior is described under subcategory F.2, Application to new problems in a different field of science. Why does water rise in the stem of this plant? How was this limestone cavern formed? How can nutriments pass through the wall of this frog's intestine? Why are there tides in the ocean?

The last application subcategory, F.3, views the student applying his knowledge and inquiry skills to problems outside of science. Included in the "outside of science" designation are technological applications. Though the distinction between science and technology in some areas of investigation is sometimes obscure, e.g. in medical research or in nuclear energy research, it still seems desirable to distinguish problems of science, where the goal is the development of understanding, from problems of technology, where the motivation is the building, designing, or production of something directly useful. How can large quantities of ammonia be cheaply made from nitrogen and hydrogen? What can be done to improve the quality of the corn produced on this farm? How can the spread of malaria in this region be checked? Will this bridge collapse if a ten ton truck passes over it? Will this black coat keep me comfortably warm in Alaska in winter? Under subcategory F.3, the applications of scientific knowledge and methods which a student can make outside of science extend virtually without limit. Not only his knowledge, but especially his skills in the processes of scientific inquiry can be applied to almost every area of human endeavor.

G. Manual Skills

The earlier discussions under categories B and C referred to such processes of scientific inquiry as making observations and measurements, selecting measuring instruments, designing experimental procedures, and subcategory A.7 concerns the student's knowledge of scientific techniques and procedures, but nowhere previously in this categorization scheme has the focus been on the student's manipulative skills in performing laboratory tasks. To the author's knowledge, no comprehensive studies have yet been made of the manual skills involved in science laboratory work in schools, but students do laboratory work nevertheless. Moreover, the student usually is expected to manipulate apparatus with some facility, to avoid hurting himself and others, and not to damage the equipment.

The two subcategories of student behaviors in category G are practically self-explanatory. Lighting and regulating the flame of a Bunsen burner is a paradigm example of subcategory G.1, Development of skills in using common laboratory equipment. Other common equipment which the student should learn to manipulate include the balance, microscope, ruler, and chemical glassware. In subcategory G.1 the emphasis is on the manual and coordinating skills the student develops as he works with various tools of the scientist's trade, whereas subcategory G.2, Performance of common laboratory techniques with care and safety, is concerned with the student's carrying-out of a sequence of manipulations toward a defined end. Examples are collecting a sample of a gas insoluble in water, preparing thin sections for microscopic examination, dissecting an animal specimen, finding the electrical resistance of a wire, determining the hardness of a mineral specimen. A student's successful performance of these and other techniques calls for them to be done carefully, so that good results are obtained, and to be carried out with sufficient attention to safety to prevent injuring both the equipment and the experimenter.

H. Attitudes and Interests

This category of student behaviors ventures into the affective domain, the domain that includes "objectives which emphasize a feeling tone, an emotion, or a degree of acceptance or rejection." This characterization is taken from page 7 of the Taxonomy of Educational Objectives, Handbook II: Affective Domain, (Krathwohl, Bloom, and Masia, 1964), and it calls attention to classes of student behaviors which undoubtedly loom large among the desired outcomes of science instruction. Category H, however, does not pretend to be a complete taxonomy of the affective domain as it pertains to the student's learning in science. While it would be most desirable to have such a taxonomy, the present lack of reliable knowledge and the primitive level of discussions about the affective domain in science education make it unlikely that an affective domain taxonomy for science can be constructed at this time. About the best that now seems possible is a categorization of aimed-for or hoped-for attitudes and interests that are frequently stated by science teachers and curriculum builders.

As the authors of Handbook II: Affective Domain repeatedly point out, wide ranges of meaning are implied or intended when the affective terms "attitude" and "interest" are used in educational circles, and they propose that the more precise terminology of their taxonomy be substituted in discussions of students' affective behaviors. Again, because of the paucity of informed, analytical discussions of affective behaviors in science education until now, implementation of this proposal is hardly feasible at present. It is already amply clear, however, that a student's attitudes and interests are always associated with cognitive elements. The student's acquisition and understanding of some significant cognitive components that underlie or accompany general attitudes and interests in science are identified in category I, Orientation.

Probably every teacher of science hopes that his students will develop favorable attitudes toward science and scientists. Some, but not all teachers consciously plan learning experiences that may promote the fulfillment of this hope, even though they realize that the development of attitudes is generally a long-term proposition. Whether the attitudes result from the efforts of a teacher or from other influences, those behaviors of the student where he manifests favorable attitudes toward science and scientists are included under subcategory H.1. If a student denounces science as a sinister enterprise or refers to scientists as "eggheads" whom he prefers to ignore, he is hardly displaying favorable attitudes. More positive expressions of feelings and, when occasions arise, actions supportive of science and scientists are wanted. No one wishes to see the student affect a fawning awe of science or an uncritical reverence of scientists. Nonetheless, it is reasonable to look for the student speaking, writing, and acting in ways which show that he places a positive value on the role of science in furthering man's understanding and that he gives due acknowledgement to scientists for their past and potential future contributions in this quest.

The next two subcategories, H.2 and H.3, relate to the student's attitudes toward scientific inquiry. Subcategory H.2 concerns his Acceptance of scientific inquiry as a way of thought. If a student accepts the processes of scientific inquiry as a valid way to conduct his thinking, his behavior in approaching a problem or novel situation is sufficiently consistent for competent observers of his actions to describe him as "behaving just like a scientist." With reference to the terminology and classifications of the Taxonomy of Educational Objectives, Handbook II: Affective Domain, the student's acceptance of scientific inquiry as a way of thought is at least at the level of

"Acceptance of a Value" (3.1), though his behavior also could be evidence of "Commitment" (3.3) or even an observable example of his "Generalized Set" (5.1). It is entirely possible that a student could engage in the processes of scientific inquiry while viewing them merely as school exercises, that he observes, measures, hypothesizes, formulates generalizations, devises and tests theoretical models without any sense of these activities being personally valuable to him and without feeling that they might be valid guidelines for his own thinking. Such a student has not accepted scientific inquiry as his way of thought. It is reasonable to conceive of scientific inquiry, fundamentally, as a state of mind. More than the mechanical performance of inquiry processes characterizes the student whose mind is attuned to inquiry. His behaviors attest that he is personally convinced that scientific inquiry is a valuable operating mode, perhaps the only valid mode for him. Under subcategory H.2 are included those behaviors which give evidence of the student's personal, cognitive-affective acceptance of scientific inquiry, with one exception. Behaviors which show that the student has adopted any of the so-called "scientific attitudes" are assigned to subcategory H.3.

Over the years an idealized folklore about scientists' personal characteristics has been promulgated which make them appear both extremely virtuous and somewhat unreal. Scientists supposedly possess certain "scientific attitudes," which include honesty, open-mindedness, self-criticism, suspending judgment, and commitment to accuracy. In actuality, the noble characteristics attributed to scientists are more a reflection of the nature of scientific inquiry and the internal social organization of science than of the personalities of scientists. What are generally known as "scientific attitudes" are better described as professional standards, to which adherence by practitioners of scientific inquiry is expected by the scientific community. Since a scientist's reported

experiments and observations can almost always be checked or duplicated by other scientists, frauds and sloppy operators are rapidly detected. When carrying out inquiries, therefore, the scientist tries to be as accurate, honest, self-critical, and open-minded as he possibly can. If he is not, he will soon lose the respect of his colleagues and may be ostracized from his profession. Institutional pressures on the scientist, rather than virtuous personal attributes, account for the "scientific attitudes" that he displays in the conduct of inquiries. The science student conducting inquiries is usually expected to imitate the scientist at work, and, hopefully, the habits of thought the scientist then displays will become a part of the student's repertoire as well. That this has occurred will at some time be indicated in the student's actions and responses in novel situations, and these behaviors are included in subcategory H.3, Adoption of habits of thought ("scientific attitudes") which ideally characterize scientists when they are engaged in inquiry.

Subcategory H.4, Enjoyment of science learning experiences, calls attention to an evidently desirable, but sadly not always evident, aspect of school science learning. Strong is the psychological evidence that students learn better, learn more, remember longer when they find pleasure in the experience. In science, the opportunities for the student to find pleasure in learning are enormous. The sight, sound, and smell of phenomena; the uncovering of a new relationship, generalization, explanation; the spark of discussions of conflicting ideas are all potential sources of involvement and enjoyment. The student who enjoys his science learning experiences will express his feelings, either in words or in other ways. Assign these expressions to subcategory H.4.

The student's interests are the focus of the last two subcategories in

category H. Under subcategory H.5, Development of interests in science and science-related activities, there are two main aspects. First are the student's interests in activities that he can carry out himself. A general criterion for a student's interest in a science or science-related activity is that he does it voluntarily and without regard to the requirements of a science course. A few examples are doing chemical experiments, collecting butterflies, building a "ham" radio receiver, experimenting with hybrid flowers. The second aspect of the student's interests in science activities concerns the attention he gives to the ongoing events in science and in the societal interactions of science. Here the student generally participates vicariously, although on occasions when a science-related issue is brought to public notice, he can demonstrate his interest through concrete action. Some examples of behavior which show that the student has interests in science activities in this second aspect are reading about new developments in solid state physics, watching a television program on cancer research, circulating a petition for preservation of a wild-life refuge.

While subcategory H.5 deals with the student's more or less transitory interests in particular science activities and with the interests of the scientifically literate person, subcategory H.6 concerns vocational interests. It is true that, in comparison with the total population at any school level, only a small proportion of students evince the inclination and aptitude for scientific or science-related careers. For the student who does, however, Development of his interest in persuing a career in science or science-related work (subcategory H.6) is a legitmate and worthy part of his learning in science. If this interest is developed by a student, his behavior in relevant situations, e.g. in responding to a vocational interests survey, will show a commitment in the direction of careers or jobs in which science is involved.

I. Orientation

As one result of recent curriculum reforms, it has become the intention of the newer science courses and programs to develop the student's appreciation of science as a human intellectual endeavor. The new programs also tend to concentrate on fostering "scientific literacy," and several direct the student's attention to the complex relationships between science and society. Taken together, these aspects of the new science programs seem to call for competencies and understandings that enlarge the student's perspective of the world, that help him to orient himself in it.

Category I, Orientation, has five subcategories, and the reader should note that a key term in four of these is "recognition," "realization," or "awareness." What is implied and intended with these terms is a certain sensitivity on the student's part to the relationships between science and other large areas of human endeavor and other ways of thought. Relationships is itallicized because these are the primary focus of the student's orientation, which enables him to perceive the enterprise of science and his study of science in a more meaningful manner. Unfortunately, space limitations preclude a discussion of these relationships here. The reader should refer to selected writings in the considerable body of literature on "scientific literacy" for explorations of the relationships indicated in the subcategories of category I. (For a bibliography of 100 referents to scientific literacy, see Pella, 1967.)

Subcategories I.1 and I.2 concern the student's orientation to some significant philosophical aspects of science. His awareness of the logical status of statements he and scientists make is the concern of subcategory I.1, Distinction between various types of statements in science (e.g., observation, interpretation, law, theory) and their relationship to one another. Our earlier

discussion of the processes of scientific inquiry, categories B through E, referred to these distinctions and relationships. They are entered again in this subcategory under Orientation to emphasize that the student should be aware of them whenever he is engaged in inquiry and when he steps back to view science in a larger perspective. This latter behavior would be a part of the student's orientation indicated by subcategory I.2, Recognition of the limitations of scientific explanation and of the influence of scientific inquiry on general philosophy. While relatively few students will wish to delve very deeply into such recondite matters, almost every student can acquire some awareness of the relationship between the kind of thinking which he practices in his science courses and alternative ways of construing the world. (For the reader interested in discussion of these matters, books such as Nagel, 1961; Nash, 1963; Walker, 1963 will be useful.)

Subcategory I.3 suggests an orientation of the student to the evolutionary character of science. Every scientific idea has a history. The history of a particular idea and the circumstances in which it is developed determine, in large measure, what the present content of the idea is and what it may become. This perspective can become a part of the orientation of any student who traces the historical development of one or more scientific ideas. The student's Recognition that the past, present, and future development of science is a product of its own history and a reflection of the general culture of its time (subcategory I.3) gives him an historical perspective on the scientific enterprise. (For further discussion, see Conant, 1951; Klopfer, 1969.)

The two final Orientation subcategories concern the relationships between science and the larger culture in which it flourishes. These relationships, referred to by some writers as the external social aspects of science, are

reciprocal. The more obvious influence of science on society is seen in the changes in man's daily life brought about by technological applications of scientific principles and ideas. Refrigerators, television, nuclear bombs, antibiotics, birth control pills are but a few examples. More subtle, and probably more fundamental, is the influence of scientific ideas on human values and man's perception of the world. The ideas of heliocentrism, the geological time scale, and evolution have greatly altered man's outlook; ideas from physiology, biochemistry, genetics applied to producing "the pill," performing organ transplants, altering human heredity raise new questions of morality. Reciprocally, society influences science and scientific inquiry. The financial support that is available from public and private agencies often determines which research problems scientists investigate. The state of technological development and the industrial capacity of a nation affect the quantity and quality of equipment and supplies available to support scientific research projects. The quality of a nation's educational system and the encouragement it gives to science study determine the number and the competence of scientists who emerge from it. A society's general intellectual climate, its attitudes toward inquiry, and the value it places on scientific work are reflected both in the number of persons who choose science as a career and in the amount of scientific inquiry the society supports.

The science student's orientation to the interactions between science and culture are summarized in subcategories I.4, Realization of the relationships existing among scientific progress, technical achievement, and economic development, and subcategory I.5, Awareness of the social and moral implications of scientific inquiry and its results for the individual, community, nation, and the world. Relating these two subcategories to category H, Attitudes and

Interests, it is noteworthy that the perspective on the relations between science and culture which he gains here complements, and provides some essential cognitive elements for, the personal perspective of the student on the relation between himself and science.

Content

The vertical dimension of the master chart presents the range of science subject-matter content that maybe included in school science programs. Though there are many possible ways of categorizing the subject matter of science, the advantages of the scheme adopted here are that it encompasses virtually all the content of school science instruction, both in traditional and modern courses, and it reflects the divisions and subdivisions of the subject that are commonly accepted by contemporary science teachers and educators. Most currect practice separates the biological sciences from the physical sciences, even though the interconnections between them are recognized, and this bifurication provides the first two categories for our content scheme. Category 3, called "General," includes those aspects of the content of science instruction which pertain to all the natural sciences.

1. Biological Sciences

The three subcategories of category 1 correspond to three levels of biological organization -- the cellular level, the organism level, the population level. These subcategories offer a convenient way of arranging the biological content of instruction, and they have been selected without prejudice to any side in the current debate over which of these or other levels of organization should have priority in children's science learning. The fact is that all three levels are represented in the biological science children now study in schools. Biological phenomena at the molecular level are also studied in some courses; these have been placed, for the most part, in content area 2.109 under the physical sciences in this categorization scheme.

Each of the subcategories has been divided further into a number of content

areas. In the following listing, specific topics and/or ideas included in each content area of the three subcategories are identified.

1.000 BIOLOGICAL SCIENCES

1.100 BIOLOGY OF THE CELL

1.101 Cell Structure and Function

Organisms are made of cells; Cell as unit of structure and function.

1.102 Transport of Cellular Material

Diffusion and osmosis; Osmoregulation, permeability, membrane phenomena.

1.103 Cell Metabolism

Basic ideas of metabolism and respiration; Intracellular metabolism.

1.104 Photosynthesis

Organismic, cellular, and biochemical aspects of photosynthesis.

1.105 Cell Responses

Regulation of cell response and cell behavior.

1.106 Concept of the Gene

Idea of an inheritable unit; Gene and gene action; DNA.

1.200 BIOLOGY OF THE ORGANISM

1.201 Diversity of Life

Variety of life; Classification of plants and animals, taxonomic relationships between plants and animals; Diversity of plant and animal forms and its implications.

1.202 Metabolism in Organisms

Ideas of breathing, digestion, etc.; Plant and animal Physiology; Metabolism in organisms and the structural adaptations involved.

1.203 Regulation in Organisms

Regulation of temperature and water balance; Homeostasis at the level of the multicellular organism.

1.204 Coordination and Behavior

Plant and animal reactions to external stimuli; Plant and animal coordination and responses, behavior; Nervous and hormonal regulation.

1.205 Reproduction and Development

Ideas of reproduction, life histories; Animal reproduction and development, metamorphosis; Plant reproduction and development.

1.206 Human Biology

Man as a living organism; Man in his physical and social environment.

1.300 BIOLOGY OF POPULATIONS

1.301 Natural Environment

Interrelationships between plants and animals in their environment; Energy relationships in ecosystems.

1.302 Cycles in Nature

Food chains and food relationships; Predators and scavengers; Food cycles, pyramid of numbers.

1.303 Natural Groups and their Segregation

Concept of natural groups; Speciation, modern taxonomy.

1.304 Population Genetics

1.305 Evolution

Basic ideas of evolution; Variation, competition, adaptation, natural selection.

2. Physical Sciences

This category is divided into three subcategories which correspond to the physical science courses most commonly offered in secondary schools -- chemistry, physics, earth and space sciences. The content areas under each subcategory include all topics taken up in traditional and modern versions of these courses. Since the physical science content of elementary and junior high school science is, in general, arranged to be propaedeutic for the courses offered in high school, the same content areas also satisfactorily serve for this educational level. The specific topics and/or ideas included in each content area are indicated in the following list.

2.000 PHYSICAL SCIENCES

2.100 CHEMISTRY

2.101 Chemical Materials

Recognition and uses of chemical materials; Division of chemical materials into heterogenous and homogenous substances, compounds, mixtures; Purification and separation of chemical materials; Extraction processes from raw materials.

2.102 Classification of Chemical Elements.

Metals vs. non-metals; Periodic table; Periodic system.

2.103 Chemical Change.

Definition of chemical change; Oxidation and reduction; Laboratory preparation of common elements and compounds; Industrial processes.

2.104 Chemical Laws.

Conservation of mass; Laws of chemical combination, stoichiometry.

2.105 Energy Relationships and Equilibrium in Chemical Systems.

Exothermal and endothermal reactions; Energy relationships,

chemical equilibrium, chemical kinetics.

2.106 Electrochemistry.

Electrolysis and ionization; Ionic equations, redox reactions.

2.107 Atomic and Molecular Structure.

Elements and compounds, atoms, molecules, Chemical bonding and chemical structure, modern atomic theories.

2.108 Introductory Organic Chemistry.

Hydrocarbons, polymerisation and polymers, esterfication, natural and synthetic processes.

2.109 Chemistry of Life Processes.

Chemistry of respiration and nutrition; Biochemical reactions, enzymes.

2.110 Nuclear Chemistry.

Nuclear reactions, radioactivity, isotopes.

2.200 PHYSICS

2.201 Kinematics.

Motion, velocity, acceleration; Vectors; Time and timing.

2.202 Dynamics.

Force, inertia, mass, weight, gravitation, momentum, friction; Newton's laws; Law of mements, equilibrium.

2.203 Energy and Its Conservation

Forms of energy, work, transformations of energy; mechanical energy, potential energy, kinetic energy; conservation of energy.

2.204 Mechanical Advantage

Lever, pulley, and inclined plane, combinations of simple

machines, types of levers; Mechanical advantage and efficiency.

2.205 Mechanics of Fluids.

Pressure, flotation; Hydrostatics, hydrodynamics, fluid flow.

2.206 Heat and Kinetic Theory.

Expansion and contraction, thermometers, transfer of heat; Change of state, latent heats; Specific heat, expansion coefficients; Gas laws; Clementary kinetic theory, thermodynamics.

2.207 Wave Phenomena.

Reflection, refraction, interference, diffraction, polarization; Longitudinal waves, transverse waves.

2.208 Sound.

Properties of sound; Instruments; Mechanical vibration, acoustics.

2.209 Light and Spectra.

Mirrors and lenses; Geometrical optics, optical instruments, photometry; Colors; Spectra; Electromagnetic spectrum.

2.210 Static and Current Electricity.

Static electricity, electrostatics; Current electricity, circuits, units, meters; Ohm's law; Direct current, electrolysis; Alterating current.

2.211 Magnetism and Electromagnetism.

Magnets and compases; Terrestrial magnetism, electromagnetism; Electromagnetic induction, transformers.

2.212 Electronics

Vacuum tubes in circuits; Thermionics, photoemission, semi-conductors.

2.213 Properties and Structure of Matter

Properties of matter; Solids, liquids, gases; Structure of molecular systems; Nuclear physics, structure of matter.

2.214 Theoretical Physics.

Relativity, wave mechanics.

2.300 EARTH AND SPACE SCIENCES

2.301 Solar System.

Earth and moon in relation to the sun, direction, seasons; Solar system, explanation of apparent solar motions; Planetary motion, Kepler's laws, Newton's explanation.

2.302 Stellar Systems.

Appearances of sky at night, constellations; Stars and galaxies, stellar distances and sizes; Cosmology.

2.303 Meteorology.

Weather phenomena; Weather maps and their interpretation, forecasting; Climate.

2.304 Physical Geology.

Earth's crust, strategraphy; Rocks and minerals, material resources, soil studies, petrology; Earth forms, deposition, erosion, weathering.

2.305 Historical Geology.

Long term processes, uniformitanism; Fossils and fossilization, palaeontology; Geological time scale and major periods.

2.306 Geophysics and Geochemistry.

2.307 Oceanography.

3. General

The third content category differs from the preceding two in that, instead of making subdivisions of the subject matter of science, it is concerned with

those broad aspects of science and science instruction that are pertinent to all the natural sciences. These general aspects have become increasingly important as a result of the recent and continuing science curriculum reforms, and it is anticipated that they will be even more emphasized in the content of newly developing programs. The descriptions of some of these content subcategories are given in an extended form to better delineate the ideas that are included.

3.010 NATURE OF SCIENTIFIC INQUIRY

OVERVIEW:

Man builds his understanding of the natural universe through scientific inquiry, which seeks orderly relationships among phenomena and develops conceptual structures that are self-testing.

3.011 Vocabulary of Scientific Inquiry:

A. Hypothesis*: a tentative statement, sometimes merely an informed guess, which expresses a scientist's conjectures about certain phenomena, or which predicts the outcome of an experiment.

B. Law*: a generalized statement concerning relationships between phenomena which has been repeatedly verified by reliable observations.

C. Theory*: a broad generalized statement, or group of statements, that seeks to correlate and explain a large number of related phenomena.

D. Experiment: an operation, or series of operations, designed to test a hypothesis or gather data under controlled conditions.

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* It is probably not important for young children to know these three technical terms in the form of definitions. What seems to be important is that a child see the differences among an educated guess, a statement which tries to pull together a mass of observational evidence, and a statement which cites a theoretical framework. Even if the child does not know the technical terms, it is possible that he can understand these differences. Building on this understanding of these distinctions, a child in the upper years of elementary school (or in junior high) should be able to use the terms accurately in applicable situations.

3.012 Scientific Knowledge

A. Scientific knowledge consists of ideas (concepts, laws, theories) about the natural world. These ideas deal primarily with what the natural world, its components, and its inhabitants are composed of and how they function and interact.

B. Scientific knowledge is tentative:

1. The ideas which make up scientific knowledge are always subject to revision.

2. At present, the ideas in many areas of science are changing rapidly.

3. When a concept or theory is found not to conform with observation or experience, the concept or theory must be modified or replaced to bring it into accord.

C. Scientific knowledge is man-made:

1. Created by human minds and efforts, scientific ideas grow and are modified as scientists expand their information and vision.

2. Scientific concepts and theories bear the imprint of the man who created them and involve his personality.

3. Individual scientists and scientists in groups cooperate to develop the ideas of science.

D. Scientific knowledge is cumulative: today's scientists build on the work of those of the past, and the achievements of the future will be based upon the accomplishments of the present.

E. Scientists do NOT claim that their theories describe an "ultimate reality".

F. The principal aim of scientific inquiry is the development of an understanding of natural phenomena in terms of verifiable laws and theories.

3.013 Unity and Diversity in Scientific Inquiry

A. There is unity in science due to a common purpose, similarity of methods, and the fact that all scientific disciplines study systems in which at least one component is biological - the observer, man.

1. Scientific inquiry always involves the application of human intelligence to the understanding of phenomena. "If there is a method in science, it is doing your damnest with your mind no holds barred." (Bridgman)

2. Scientific inquiry involves thought (--planning, analyzing, interpreting, evaluating--) as well as action (--setting up experiments, performing manipulations, making observations--). Carrying out experimental tests and making observations to check his predictions are the scientist's way of asking questions of nature.

3. A scientist's work never ends: the solution of one problem leads invariable to new problems.

B. There is diversity in scientific inquiry due to the fact that different scientific disciplines study different systems (--i.e., different objects and phenomena are investigated by different disciplines--) and employ different theoretical structures.

1. Scientific disciplines can be classified into two major, relatively distinct types:

   a. those having a strong temporal or historical element and for which both reductionist and compositionist theories are needed -- principally evolving sciences, e.g., ecology, psychology.

   b. those for which the temporal or historical element is largely ignored and for which reductionist theories seem adequate -- the so-called exact sciences, e.g., physics, chemistry.

2. In any scientific discipline, there are two different forms of scientific inquiry: the "stable" form and the "fluid" form. One form of inquiry or the other, or sometimes both, may be proceeding in a discipline at any particular time.

   a. When scientific inquiry proceeds without altering the the theoretical structure of the discipline, it is said to be normal, stable, or completive inquiry. The great bulk of scientific inquiry is of this form.

      (1) stable inquiry - "constructing an edifice without questioning the plan" (Schwab)

      (2) knowledge is cumulative in the simple sense of accretion.

   b. When scientific inquiry makes necessary or forces a change in the theoretical structure of the discipline, it is said to be extraordinary, fluid, or generative inquiry. This form of inquiry produces what are called "revolutions" in science. In certain disciplines, these revolutions have recently become quite frequent.

      (1) fluid inquiry - "a mode of investigation which rests on conceptual innovation, proceeds through uncertainty and failure, and eventuates in knowledge which is contingent, dubitable, and hard to come by." (Schwab)

(2) Since scientists are seeking explanations of natural phenomena in terms of abstract ideas, it is inevitable that different interpretations of a group of phenomena will arise. At such times, there will be disagreements and controversies among scientists about the interpretation which best fits the observations. Such controversies provide stimulus to further research, as scientists seek evidence to resolve the conflict.

(3) Acceptance of a new theory is much like a change in gestalt in which the elements being interpreted are constant but a switch in interpretation occurs requiring abandonment of that previously held in favor of one completely different. Literally, a new world opens up.

3.014 Self-Testing Aspects of Scientific Inquiry

A. The most widespread and conclusive process of self-testing in science is testing by multiplication of relevant observations. Scientists generally test hypotheses in this way.

1. Relevant observations are those which are potentially capable of disproving the hypothesis.

a. Prediction is only a special form of relevant observation: that for which failure to occur would disprove the hypothesis.

b. Prediction is possible only when the terms being used have been given their operational definitions.

c. Prediction is more difficult in biology which often deals with unique events.

2. When the scientist is satisfied that the results of multiple observations fall within the range predicted by his hypothesis, he will accept the hypothesis as correct. If the results do not fall in the predicted range, he must reject the hypothesis.

B. Observations, laws, or theories may lead a scientist to predict certain phenomena and behaviors in nature, and he must question nature to find out whether his predictions (hypotheses) are correct.

1. The relationship of theory to observation is crucial -- without theory, man does not know what to observe.

2. The observations that are to be made in experimental testing must be expressed in terms of specified variables.

a. In experiments where all possible variables cannot be clearly identified, it is desirable to use controls. In a simple control experiment, the control sample is treated exactly the same as the experimental sample except for the experimental variable being investigated.

b. With many phenomena, the whole point of observation is not an exact measurement of determination of occurance but establishment (to some degree of confidence) of a probability.

c. Scientists doing research frequently require specialized instruments and equipment to carry out experiments and make observations.

(1) As experiments become more precise and sophisticated, improvements must be made in the scientific instruments and equipment employed.

(2) Introduction of a new instrument or technique may lead to a new epoch of progress in developing scientific ideas.

C. Falsification is an important process of self-testing in scientific inquiry. Ideas and facts that remain as accepted parts of science have been shown to be not false.

1. The falsity of an alleged face or theory in science can be determined through observation and experiment although the scientist cannot know whether the theory or fact is "true" in an absolute sense. For a scientific fact or theory to be accepted by scientists, it must be shown to be not falsified by evidence that has been gathered.

a. Science has selected, as its criteria for truth, sense data which can be comprehended and checked by everybody with appropriate training.

b. If an alleged fact is false, it will be detected by multiple observations of the same phenomena by different persons. An alleged fact is accepted when multiple observations by different people concur.

2. A theory is held to be valid to the extent that observations check with deductions derived from it. If observations do not check with predictions made from a theory, it may be modified by scientists, it may be held with restricted scope, or it may be discarded in favor of a more adequate theory.

a. If a scientific theory or some part of it is false, it will predict phenomena that cannot be found through experiments and observations by competent investigators.

b. To be of value and interest in science, a theory must allow prediction of a large number of apparently unrelated observations.

c. Simplicity, explanatory power, and growth potential all contribute to the acceptance of a theory.

3.020 SOCIAL ASPECTS OF SCIENCE

3.021 Interactions of Science with Society.

OVERVIEW: The interactions of science with society are reciprocal: science has marked influences on the culture in which it exists; at the same time, the cultural environment of the society-at-large influences the development of science.

A. Interdependence of Science, Technology, and Society.

1. Science is dependent upon technology for tools and techniques and, frequently, for the formulation of basic questions. In some fields, the separation between science and technology is relatively non-existent.

2. Technology depends upon basic science for the development of new knowledge and understanding.

   a. The ability to generate new scientific knowledge and to apply it in technology is a major factor in the economic growth of all nations throughout the world today.

   b. Social and political changes may need to be made in a nation for it to keep pace with scientific and technological advances.

3. Many contemporary social, economic, and political problems have rational solutions only in the context of science and technology.

B. Influences of Science on Society.

1. The evolution of scientific ideas and scientists' achievements in understanding the natural world have greatly affected, and will continue to affect, the conditions of people in a society:

   a. The influence of scientific ideas on human thought are reflected in changes in orientation and in the content of literature and philosophy. Science contributes to man's common-sense view of the world.

   b. Applications of scientific laws and principles accelerate, and often make possible the development of an efficient technology. Expanding technology, in turn, produces many economic readjustments and opportunities with their concomittant sociological changes.

      (1) Increased population, "automated unemployment", and nuclearphobia are only a few of the societal problems created by science and technology.

(2) There are vocational and leisure implications of scientific discovery and technological development.

c. Applications of scientific ideas to problems of human health and disease help to alleviate people's suffering and often produce significant changes in demographic characteristics of society.

C. Influences of Society on Science.

1. Science is, in large measure, a product of the prevailing culture of the society in which it exists.

a. Factors which determine how well science will flourish in a particular society include:

(1) the conduciveness of the general climate of opinion to the kind of inquiry which scientists pursue;

(2) the maintainance of an adequate educational system to train scientific investigators and supporting personnel;

(3) the provision of sufficient financial backing for science personnel, materials and institutions;

(4) the state of development of supporting industries which supply instruments, equipment, and materials needed in scientific work.

b. Since the factors mentioned in paragraph a. vary from country to country and from time to time, the extent of scientific activity and achievements vary from one nation to another and throughout the history of any one nation.

2. The needs and interests of a nation often determine the kinds of problems scientists will investigate.

3.022 Organization of the Scientific Enterprise

OVERVIEW: Scientific work is carried out within the context of a cooperative, internally-regulated social institution.

A. The institutionalized goals of science are the extension of knowledge and the explanation of natural phenomena.

1. The primary concern of science is the understanding of nature: the extension of this knowledge to practical applications is an important by-product.

2. In the search for knowledge and understanding, science is a process-oriented, dynamic activity.

3. To further the goals of science, scientists collaborate in their efforts on an international scale.

   a. The origin of a contributor to science is unimportant; it is his contribution that counts.

   b. Validation of ideas is an international endeavor: there is no proper place for nationalism in science.

B. The guidelines regulating scientific activities constitute an unwritten set of values (an "ethos") for the scientific community.

   1. The validity of ideas must be subjected to critical appraisal by other qualified investigators. Careful validation of ideas makes it possible for researchers to build on previous work with considerable confidence.

   2. The substantive findings of science are a product of community collaboration and are part of the public trust.

   3. Scientists are expected by their peers to achieve their self-interest in work-satisfaction and in prestige through direct service to the community of scientists.

   4. Institutional pressures on scientists.

      a. Many of the noble characteristics attributed to scientists are more a reflection of the nature of the scientific enterprise than of the personalities of scientists. What are generally known as "scientific attitudes" are better described as professional standards. The nature of scientific evidence is such that observations and experiments can almost always be checked or duplicated by other scientists, so that frauds and sloppy operators are rapidly detected. In the laboratory, therefore, the scientist will be as accurate, honest, self-critical, and open-minded as he possibly can. If he isn't, he will soon lose the respect of his colleagues.

         (1) A scientist expects his ideas to be challenged.

         (2) Validation of ideas eliminates quacks and charlatans from scientific work.

      b. Another institutional pressure on scientists is to be creative. The scientist cannot be merely a recorder of observations, for a large task in science is the development of new ways of thinking about what is observed and new techniques for observing. Thus, a definite creative effort is demanded of the scientist. This demand accounts for the appearance of certain personality tendencies among scientists, since creativity is a function of certain personality attributes, and non-creative people do not stay active as scientists.

5. Controversies in science are resolved in the open forum (either in meetings or through publications) of the professional group. A scientist's views are always subjected to the informed criticism of his colleagues, and it is expected that he should present all relevant evidence, appeal to experimental and observational data, and rely on logic, not rhetoric.

   a. Scientists communicate with one another through meetings, journals, books, personal contacts, correspondence. Informal and formal contacts among scientists are equal in importance. Ideas, opinions, and speculations are clarified and grow through informal give-and-take, letters, discussions.

   b. Publications make it possible for a scientist's work to be critically scrutinized by his colleagues and to be subject to repeated tests.

3.030 HISTORICAL DEVELOPMENT OF SCIENCE

OVERVIEW: The ideas and status of contemporary science are the result of the past development of science and of historical events in society.

A. The growth of science stems from man's compelling desire to understand himself and his environment.

   1. As civilized man's principal means of biological adaptation, science is an evolutionary specialization that arose from more primitive, prescientific means of cultural adaptation, which in turn had arisen from still more primitive, prehuman behavioral adaptation.

   2. Modern science is a recent development in the history of mankind.

   3. Modern science is a product of the changes in human thought since medieval times.

      a. Science has accelerated and intensified the changes in human thought in the last four centuries.

      b. Certain historical and philosophical developments have influenced scientific thought.

   4. The profession of scientist developed as one result of the general societal trend toward specialization during the past 150 years.

   5. The needs and interests of a society at a particular period of history often influence the kinds of problems that scientists will investigate. This is particularly true in areas where practical applications can be foreseen for potential scientific discoveries.

6. The growth of scientific ideas is closely related to the development of instruments and special techniques.

   a. Instruments extend man's senses and enable the scientist to see more, both literally and figuratively, than he could without them.

   b. Introduction of a new instrument or technique into a field of science may lead to a new epoch of progress.

   c. As investigations in a field of science become more precise and sophisticated, improvements must be made in the specialized instruments, equipment, and techniques employed in carrying out experiments and making observations.

B. Theories, laws, and concepts of science are dynamic and change is self-accelerating.

1. The growth of ideas over time is characteristic of science. In science answering one question raises many others.

2. Modern science is growing exponentially.

   a. The "redoubling rate" in science is currently less than a decade.

   b. At present, theoretical ideas in many areas of science are changing rapidly.

3. Science is not, and probably never will be a finished enterprise: there remains always more to be discovered, and new ideas will be forthcoming.

4. The trend in all sciences is for them to become increasingly theoretical and exact, the biological sciences being currently more correlational and the physical sciences more exact. Models have become increasingly abstract and theoretical -- physical models give way to mathematical models.

   a. The development of inquiry in biology is movement from simple observation, to taxonomy, to descriptive morphology, to the addition of analysis to description. Some biologists are attempting to move toward deductive patterns of thought and to the development of deductive theories, i.e. explanatory systems that will be predictive.

   b. Scientific theories considered to explain "why" become, in the course of time, to be considered as descriptions of "how." Newer, more comprehensive theories then give "why."

3.040 BIOGRAPHIES OF SCIENTISTS

OVERVIEW: Men and women possessing a variety of personal characteristics and abilities carry out the diverse tasks in the science professions.

A. Personal Characteristics of Scientists.

1. Like any group of people, scientists differ with respect to their personal characteristics. They differ, for example, in how they approach and handle personal problems, in how they relate to their wives or husbands and their families, in their interests in fields of endeavor outside science (e.g., music, politics). Hence, there is little factual basis for some of the popular stereotypes of scientists.

2. Many generalizations about scientists are tendencies of successful professional people in general (e.g., dedicated to his or her work, extremely hard-working).

3. As a group, scientists are above-average in general intelligence.

4. Scientists do not necessarily display "scientific attitudes" when they are not engaged in their work. As human beings, scientists are subject to the same human weaknesses, temptations, and emotions as are people in other lines of work.

B. Abilities of Scientists.

1. Since the activities of different scientists vary over a wide range, it is not possible to define a single set of specific abilities needed by all scientists. A scientist will need different abilities, depending on the field he works in and on whether he is primarily a theoretician or an experimenter.

2. Some scientists, who are primarily theoreticians, rarely, or never, perform experiments: their principal activity is the synthesizing of scientific knowledge and the construction of theories.

3. Some general abilities often needed by scientists are:
   a. ability to communicate effectively;
   b. ability to think critically;
   c. ability to observe and record accurately;
   d. ability to design experiments and apparatus;
   e. manipulative skills;
   f. facility in mathematics;
   g. ability to see problems in a broad perspective.

4. Today, scientific research is so complex that long years of training are needed to prepare for most types of work. This training usually includes several years of formal study after graduation from college.

3.050 MATHEMATICS IN SCIENCE

OVERVIEW: Mathematics plays an essential role in science, both in the practical aspects of carrying out investigations and in the development of theories.

3.051 Mathematical Concepts, Definitions, and Terminology.

A. Arithmetic

B. Algebra

C. Geometry

D. Trigonometry

E. Probability

F. Calculus

3.052 Mathematical Procedures and Algorisms.

A. Arithmetic computations

B. Algebraic procedures

C. Statistical computations

D. Differentiation and integration

3.053 Mathematical Models.

3.060 MEASUREMENT.

A. Measurement of number, length, mass, time, temperature.

B. Combinations of basic measurements: volume, density, speed, growth rate, specific heat, etc., etc.

C. Standards and systems of units.

D. Errors of measurement.

3.070 SYSTEMS

OVERVIEW: A system is a complex of interacting parts which collectively exhibits certain behavioral characteristics. The interacting parts of a system may themselves be thought of as systems (or subsystems), which may have a hierarchical structure.

(The following summary of basic concepts relating to concrete systems is adapted from Miller, 1965, pp. 202-204.)

A. Concrete Systems and Subsystems.

1. A concrete, real, or veridical system is a nonrandom accumulation of matter-energy, in a region in physical space-time, which is nonrandomly organized into coacting, interrelated subsystems or components.

2. The units (subsystems, components, parts, or members) of these concrete systems are also concrete systems.

3. Relationships in concrete systems are of various sorts, including spatial, temporal, spatiotemporal, and causal.

4. Both units and relationships in concrete systems are empirically determinable by some operation carried out by an observer.

5. The observer of a concrete system distinguishes a concrete system from nonorganized entities in its environment by the following criteria: (a) physical proximity of its units; (b) similarity of its units; (c) common fate of its units; and (d) distinct or recognizable patterning of its units. He maintains that evolution has provided human observers with remarkable skill in using such criteria for rapidly distinguishing concrete systems. Their boundaries are discovered by empirical operations available to the general scientific community rather than set conceptually by a single observer.

B. Variables of a System.

1. Any property of a unit or relationship within a system which can be recognized by an observer who chooses to attend to it, which can potentially change over time, and whose change can potentially be measured by specific operations, is a variable of a concrete system. A variable is intrasystemic, and is not to be confused with intersystemic variations which may be observed among individual systems, types, or levels.

2. The state of a concrete system at a given moment is represented by the set of values on some scale which its variables have at that instant. This state always changes over time.

C. Open and Closed Systems.

1. Most concrete systems have boundaries which are at least partially permeable, permitting sizeable magnitudes of at least certain sorts of matter-energy or information transmissions to cross them. Such a system is an open system. In open systems entropy may increase, remain in steady state, or decrease.

2. A concrete system with impermeable boundaries through which no matter-energy or information transmissions of any sort can occur is a closed system. This is a special case, in which inputs and outputs are zero, of the general case of open systems. No actual concrete system is completely closed, so concrete systems therefore are relatively open or relatively closed. In closed systems, entropy generally increases, exceptions being when certain reversible processes are carried on which do not increase it.

D. Nonliving and Living Systems.

1. Every concrete system which does not have the characteristics of a living system is a nonliving system. This is the general case of such systems, of which living systems are a very special case.

2. The living systems are a special subset of the set of all possible concrete systems, composed of the plants and the animals. They all have the following characteristics:

(a) They are open systems.

(b) They maintain a steady state of negentropy even though entropic changes occur in them as they do everywhere else. This they do by taking in inputs of matter-energy higher in complexity of organization or in negative entropy, i.e., lower in entropy, than their outputs. Thus they restore their own energy and repair breakdowns in their own organization.

(c) They have more than a certain minimum degree of complexity.

(d) They contain genetic material composed of deoxyribonucleic acid (DNA), presumably descended from some primordial DNA common to all life, or have a charter, or both.

(e) They are largely composed of protoplasm (containing water and proteins, constructed from about a score of amino acids and other characteristic organic compounds) and its derivatives.

(f) They contain a decider, the essential critical subsystem which controls the entire system, causing its subsystems and components to coact, without which there is no system.

(g) They also contain certain other specific critical subsystems or they have symbiotic or parasitic relationships with other living or nonliving systems which carry out the processes of any such subsystem they lack.

(h) These subsystems are integrated together to form actively self-regulating, developing, reproducing unitary systems, with purposes and goals.

3. Living systems can exist only in a certain environment. Any change in their environment of such variables as temperature, air pressure, hydration, oxygen content of the atmosphere, or intensity of radiation, outside a relatively narrow range which occurs on the surface of the earth, produces stresses to which they cannot adjust. Consequently they die.

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